



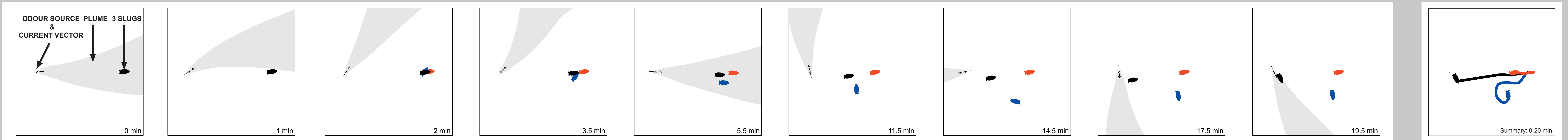
Can odour gated rheotaxis be improved for navigation in variable flow?

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COMPARISON: Three sea slugs start at the same location, 2 m distant from an odour source, and then use three strategies for to find the source.



Strategies: Red = strict odour gated rheotaxis; Blue = odour gated rheotaxis + rheotaxis for 10 min after plume lost; Black = odour gated rheotaxis + last known heading for 10 min after plume lost

CONCLUSION: the best search strategy is odour gated rheotaxis supplemented by following the last known heading once the odour plumes is lost

Introduction

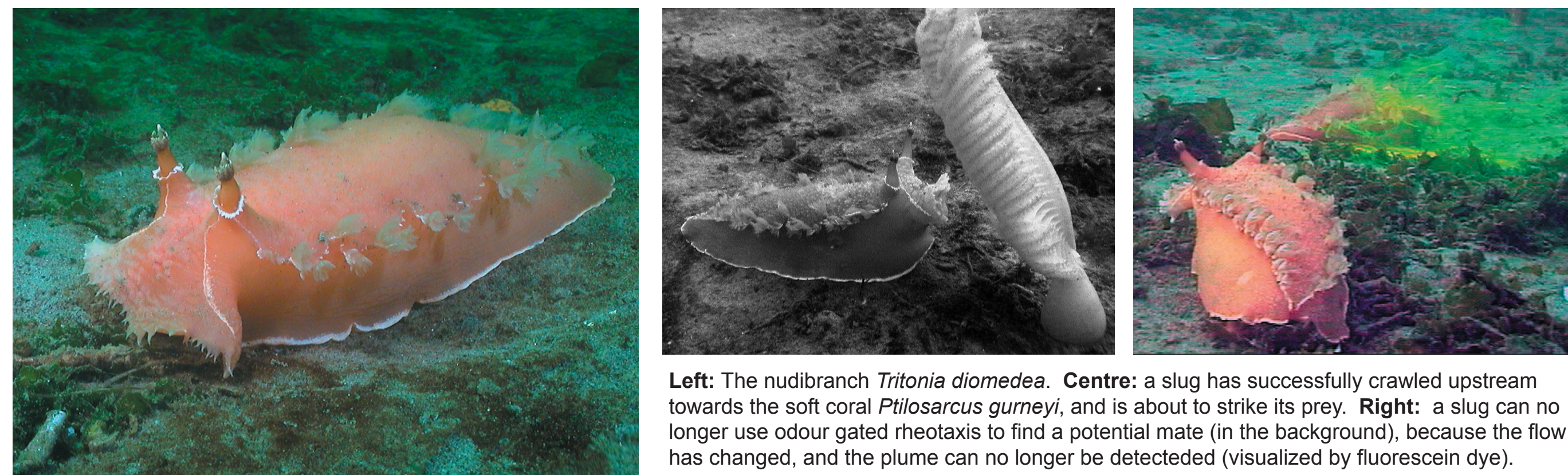
•Many animals use odour gated rheotaxis to navigate

In most situations, the effects of flow (advection and turbulence) destroy any diffusive odour gradients, eliminating chemotaxis as a navigational option. Instead, animals move upstream in the presence of odour. This strategy succeeds because flow transports the odour from the source to the animal^{1,2,3}.

•Slow moving animals may have a problem

If bulk flow direction changes before the animal reaches the odour source, then following the flow will lead the animal astray. The severity of the problem will depend on the time scales over which animals search and flow varies.

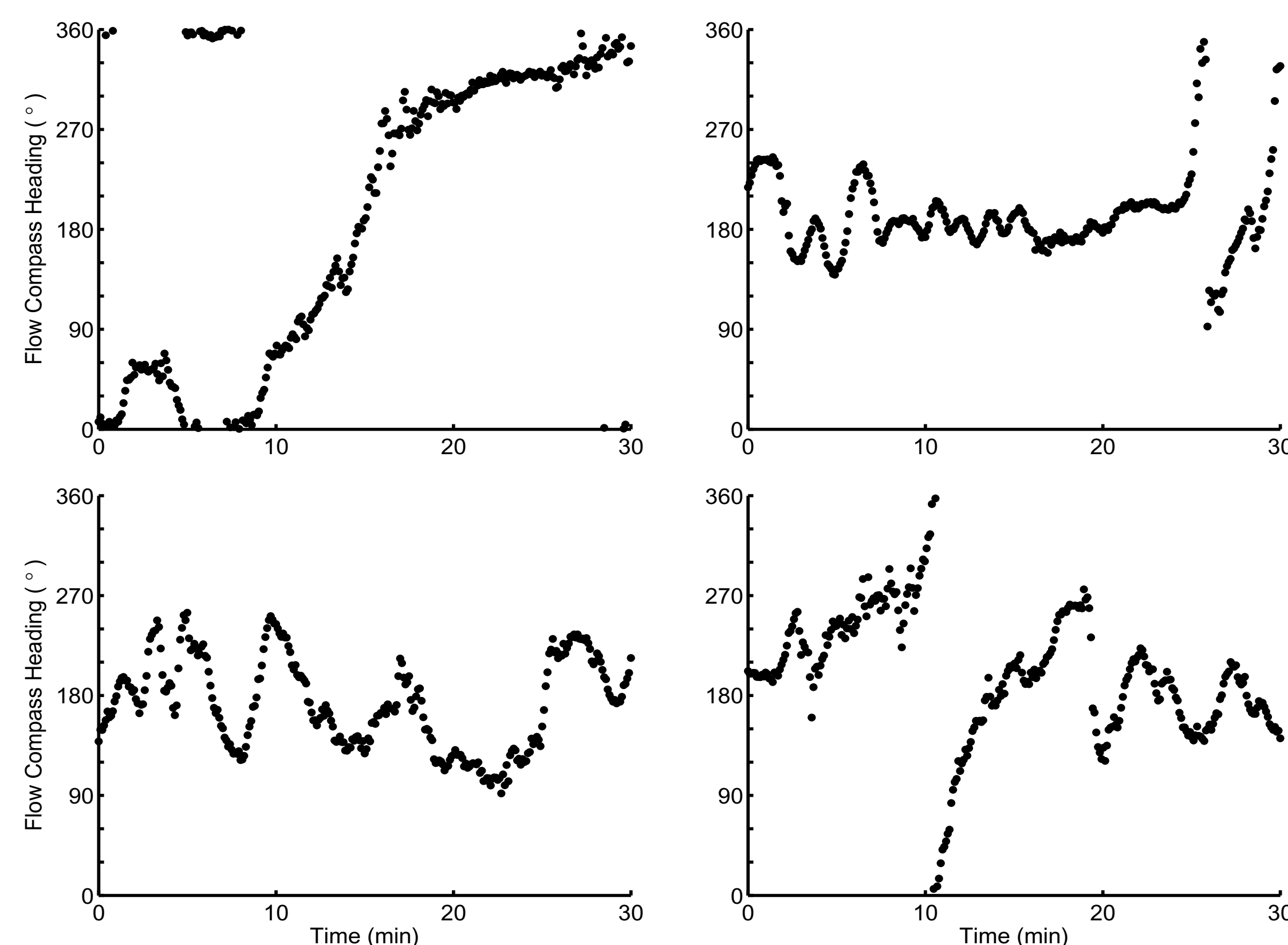
•Tritonia diomedea uses odour plumes to find prey and mates^{4,5}



Left: The nudibranch *Tritonia diomedea*. Centre: a slug has successfully crawled upstream towards the soft coral *Polysarcus gurneyi*, and is about to strike its prey. Right: a slug can no longer use odour gated rheotaxis to find a potential mate (in the background), because the flow has changed, and the plume can no longer be detected (visualized by fluorescein dye).

The slug is slow (10 cm/min) and blind (navigation must use odours and flow).

•Flow in the slugs' habitat varies considerably



Four examples of flow patterns in the slugs' habitat where frequent direction changes of more than ~30° (the amount by which plumes spread) could render odour gated rheotaxis unusable as an odour source search strategy.

•Could flow variability impact navigation on average?

Changes in flow direction large enough to move an odour plume away from a navigating slug occur every 5 to 15 minutes, on average⁵. Strict odour gated rheotaxis can therefore only work over 0.5 - 1.5 m for the slugs. Although this may work to find prey, conspecifics are often more widely separated.

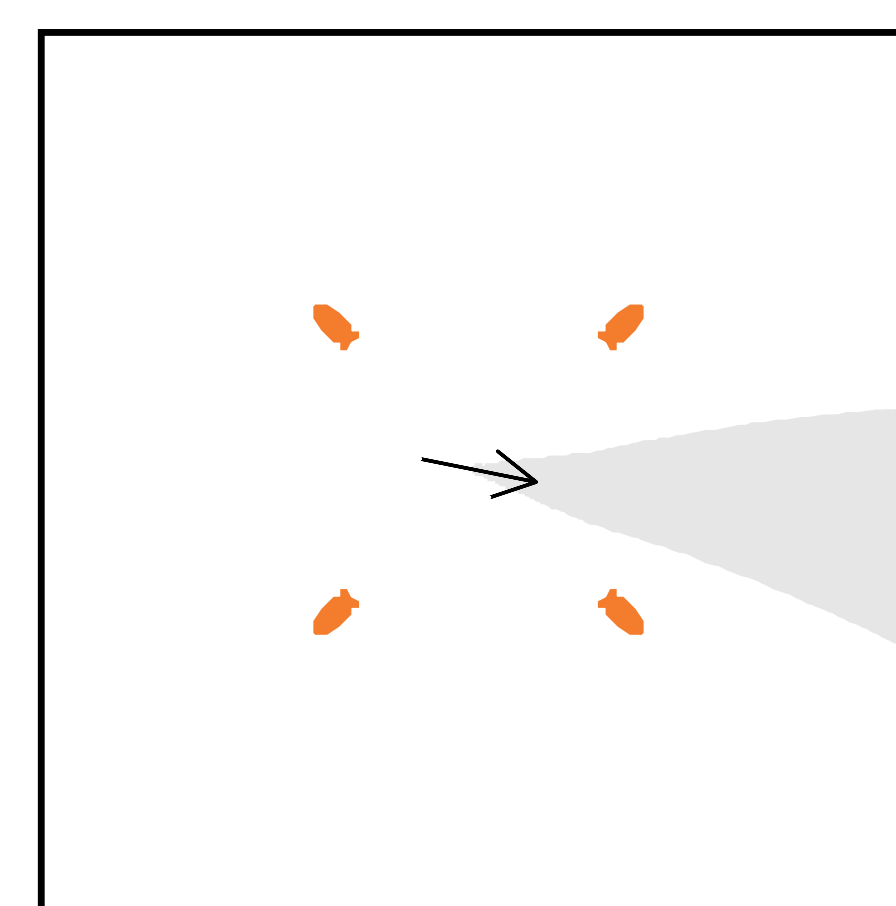
Last-Known-Heading Hypothesis

•Navigating *Tritonia diomedea* could benefit from following the last known heading from which odour was detected.

Could this strategy improve odour gated rheotaxis given the pattern of natural occurring flow variations and slug locomotory abilities?

Modelling Methods

•Numerical model of different odour source search strategies



- ▶ 2-dimensional, continuous space
- ▶ discrete time steps
- ▶ one central odour source
- ▶ flow moves odour from source through the space
- ▶ slug movements are a biased random walk
- ▶ different strategies defined by different responses to odours, flow, or past experience

•Model parameters are based on measurements from the field

Flow: real half-hour current heading data sets (4 shown in left column)
Slugs: crawling and turning speeds, etc. measured from behaviour videos
Odours: plumes will spread similarly to dye plumes (~30° in this habitat)

•Strategy comparison:

- OGR** = odour gated rheotaxis supplemented by further rheotaxis for 0, 1, 2.5, 5, or 10 min after odour plume is no longer detected
- LKH** = odour gated rheotaxis supplemented by following last known heading from which odour detected for 0, 1, 2.5, 5, or 10 min after odour plume is no longer detected
- Blstc** = odour gated rheotaxis supplemented by ballistic crawling for 0, 1, 2.5, 5, or 10 min after odour plume is no longer detected

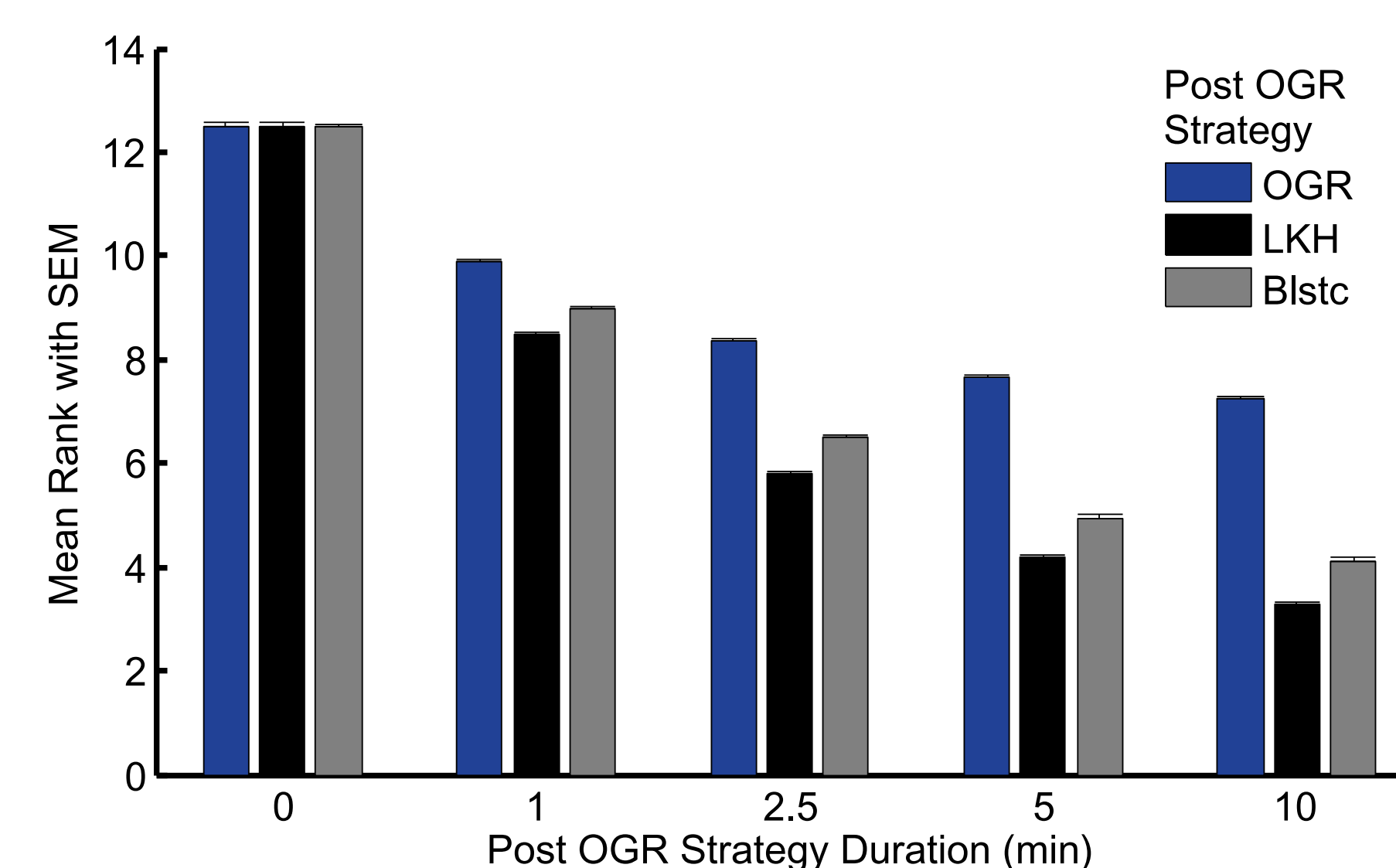
•Strategy performances measured across multiple starting positions and multiple current data sets

4 initial headings x 8 points around source x 3 distances from source = 96 slugs tested for each strategy across 88 different current data sets

•Strategies were ranked according to how close slugs same starting from the same position came to the odour source

Results

•Best Strategy: supplementing odour gated rheotaxis by following the last known heading from which odour was detected



Relative rankings of the different strategies (lower rank = closer to the source)

- LKH** = odour gated rheotaxis supplemented by following last known heading
- Blstc** = odour gated rheotaxis supplemented by ballistic crawling
- OGR** = odour gated rheotaxis supplemented by rheotaxis

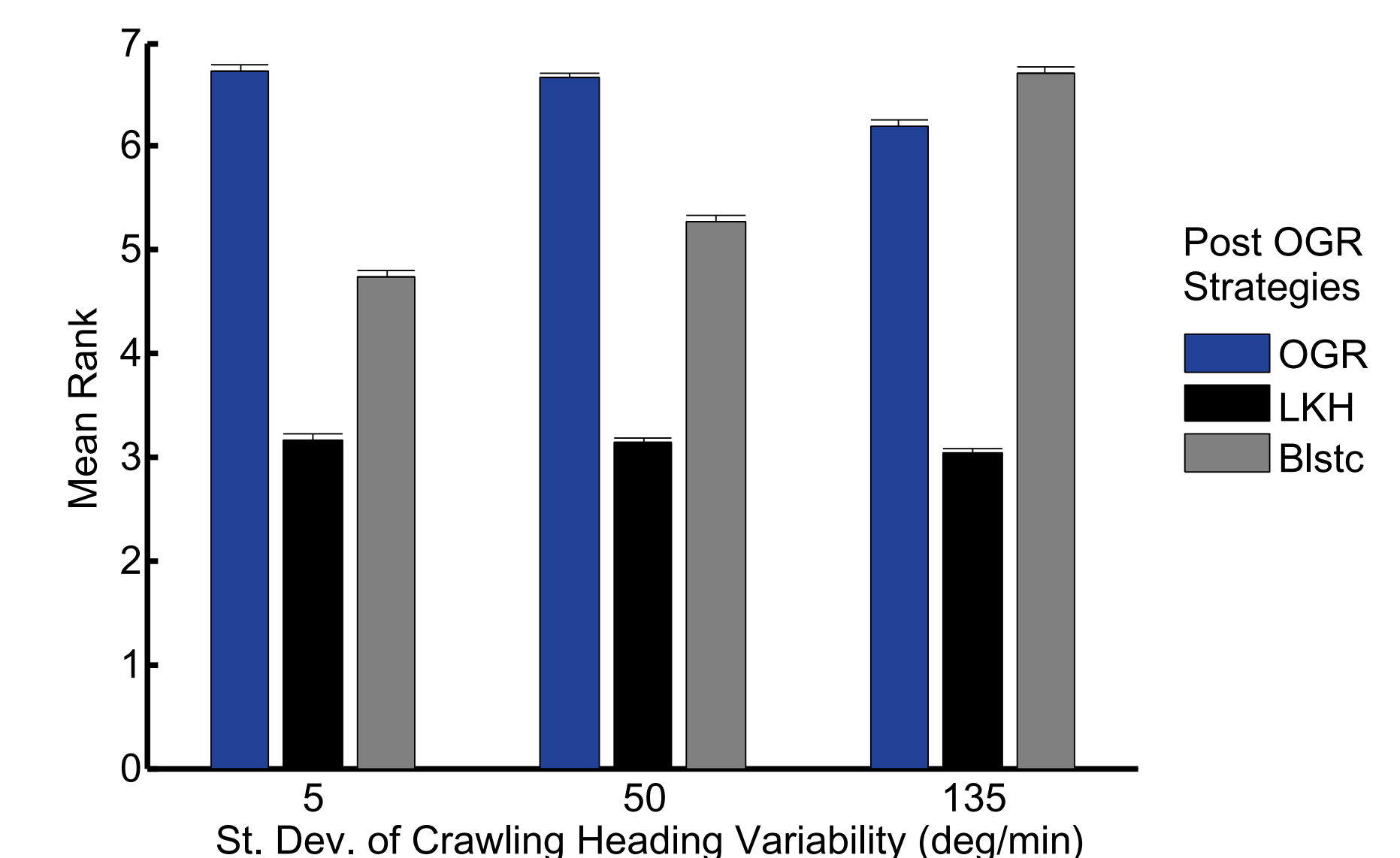
Following the last known heading is consistently the best strategy, and performs better the longer the slug follows that heading once the scent is lost.

Results cont'

•Following the last known heading is the best strategy, regardless of the choice of a key parameter:

The effective odour plume spread (this depends on turbulent diffusion and the slugs' odour detection threshold) has no substantial effect on the rankings.

•Ballistic crawling performs better than continuous rheotaxis only while random variation in crawling heading is low



Rankings of the 10 min strategies at 3 levels of variation in crawling headings.

- LKH** = odour gated rheotaxis supplemented by following last known heading
- 2 or 3. Blstc** = odour gated rheotaxis supplemented by ballistic crawling
- 3 or 2. OGR** = odour gated rheotaxis supplemented by rheotaxis

Ballistic (unguided) crawling can improve on strict odour gated rheotaxis provided random perturbations do not divert the animal from a straight line..

Conclusions and Implications

•Tritonia diomedea may supplement odour gated rheotaxis by following the last known heading from which odour was detected when navigating towards an odour source.

The next step is to observe in the field whether slugs abandon rheotaxis when navigating towards a mate when bulk flow direction changes occur.

•A guidance mechanism for following the last known heading could be important, suggesting an 'orienting' role for magnetosensation in *Tritonia diomedea*^{6,7}. Further experiments will test whether magnetosensation is involved in finding odour sources in variable flow.

•Other animals encountering changes in bulk flow that stall odour gated rheotaxis may also exploit alternate cues to follow the last known heading to find an odour source.

References

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Acknowledgements

National Sciences and Engineering Research Council, Nova Scotia Health Research Foundation, R.P. Croll, A.O.D. Willows, S.D. Cain; J.Murray, O.M. Woodward, C.P. Holmes